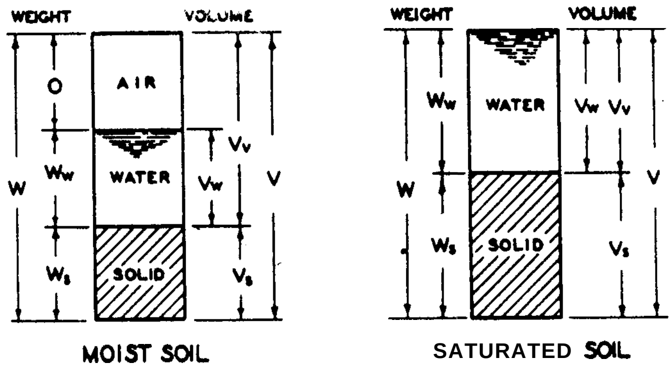
APPENDIX II:

UNIT WEIGHTS, VOID RATIO, POROSITY, AND DEGREE OF SATURATION

1. RELATIONS. A soil mass is considered to consist of solid particles enclosing voids of varying sizes. The voids may be filled with air, water, or both. The fundamental relations of the weights and volumes of the various components of a soil mass can be derived using the simplified sketches shown in Figure 1. Some of the more important relations used in soils engineering calculations are unit weights, void ratio, porosity, and degree of saturation. The quantities which must be known to compute these relations are the weight and volume of the wet specimen, the weight of the same specimen after oven-drying, and the specific gravity of the solids (see Appendix IV, SPECIFIC GRAVITY). The weights of the specimens usually can be obtained without difficulty. The volume of the wet specimen is determined by linear measurement (volumetric method), or by measurements of the volume



WATER CONTENT $w = \frac{W_w}{W_s}$

DRY UNIT WEIGHT (DRY DENSITY) $\gamma_d = \frac{W_s}{V}$

WET UNIT WEIGHT (WET DENSITY) $\gamma_m = \frac{W}{V}$

VOID RATIO $e = \frac{V_v}{V_s}$

POROSITY $n = \frac{V_v}{V} = \frac{e}{1+e}$

DEGREE OF SATURATION $S = \frac{V_w}{V_v}$

SPECIFIC GRAVITY OF SOLIDS $G_s = \frac{W_s}{V_s \cdot \gamma_w}$

NOTE: UNIT WEIGHT OF WATER. γ_w = 62.4 LB/CU FT.

Figure 1. Fundamental relations

or weight of water displaced by the specimen (displacement method). Definitions of the relations to be determined and detailed procedures for determining these values, using the volumetric and displacement methods, are given in the following paragraphs.

2. DEFINITIONS. The unit weights, void ratio, porosity, and degree of saturation are defined below.

a. Dry unit weight, γ_d, or dry density, is the weight of oven-dried soil solids per unit of total volume of soil mass, and is usually expressed in pounds per cubic foot.

b. Wet unit weight, γ_m, or wet density, is the weight (solids plus water) per unit of total volume of soil mass, irrespective of the degree of saturation (see e below). The wet unit weight is usually expressed in pounds per cubic foot.

c. Void ratio, e, is the ratio of the volume of voids to the volume of solid particles in a given soil mass.

d. Porosity, n, is the ratio (usually expressed as a percentage) of the volume of voids of a given soil mass to the total volume of the soil mass.

e. Degree of saturation, S, is the ratio (expressed as a percentage) of the volume of water in a given soil mass to the total volume of voids.

3. VOLUMETRIC METHOD. a. Description. The volumetric method consists of computing the total volume of soil from linear measurements of a regularly shaped mass. In general, the method is applied to soils which can be cut or formed into a cylinder or parallelepiped. Specimens of this type are used for other laboratory tests, and methods for preparing them are described under the individual test procedures. The procedure presented below is based on obtaining a cylindrical specimen by progressive trimming in front of a calibrated ring-shaped specimen cutter. However, other methods for obtaining a regularly shaped mass, such as cutting and trimming or punching, can often be used successfully. The

volumetric method should not be used for soils containing gravel, shells, or foreign materials which would interfere with advance trimming. The calibrated specimen cutter method is particularly suitable for obtaining volumes of silty and sandy soils having little cohesion.

b. Apparatus. The apparatus should consist of the following:

(1) Calibrated ring-shaped specimen cutter, hereinafter referred to as a volumetric cylinder. Types and sizes of volumetric cylinders may vary widely; two types are shown in Figure 2. General requirements are that a volumetric cylinder be made of materials not susceptible of rapid corrosion and that it be as large as possible in relation to the samples being tested. The inside of the cylinder should be polished to a smooth finish, and sharp cutting edges should be provided on the base. It is very important that no voids form between the sample and cylinder; to facilitate detection of such voids, a volumetric cylinder of transparent Lucite with detachable steel cutting edges may be used.

(2) Guide cylinder for guiding cutter into soil (not absolutely necessary).

(3) Trimming tools, such as wire saw, straightedge, or knife.

(4) Oven (see Appendix I, WATER CONTENT - GENERAL).

(5) Specimen container. The container should be of metal that is resistant to corrosion. Seamless aluminum pans with lids are satisfactory.

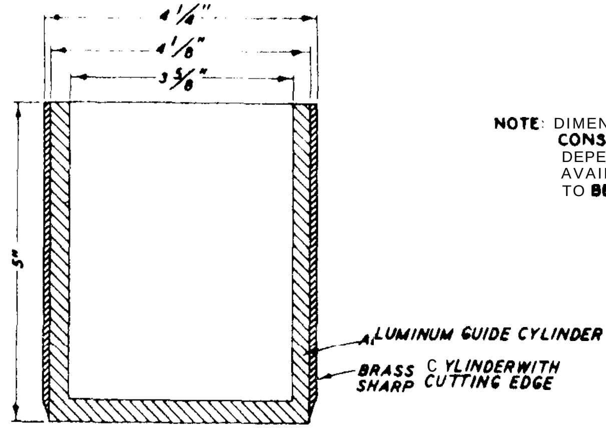
(6) Balance, sensitive to 0.1 g.

(7) Glass plate, large enough to cover top of specimen.

c. Procedure. The procedure shall consist of the following steps:

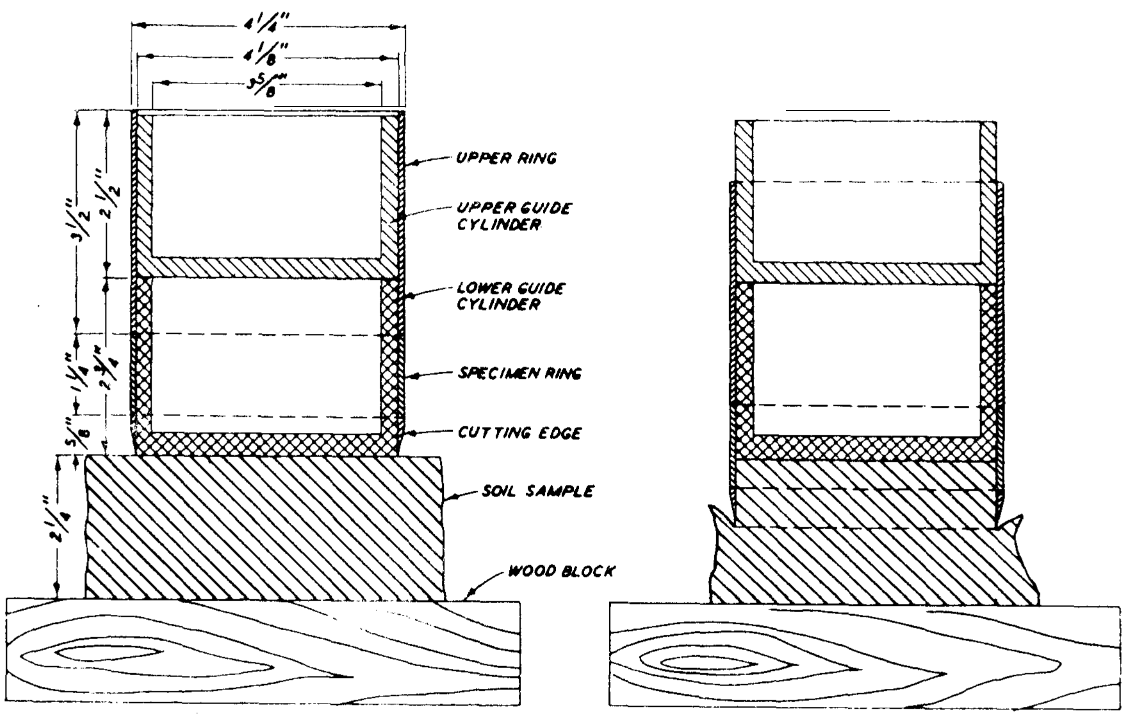
(1) Record on a data sheet (Plate II-1 is a suggested form) all identifying information for the sample, such as project, boring number, and other pertinent data.

(2) Measure and record the height, H, and inside diameter, D, of the volumetric cylinder. In general, linear measurements shall be



NOTE: DIMENSIONS AND MATERIALS OF CONSTRUCTION MAY VARY DEPENDING ON SIZE OF SAMPLES AVAILABLE AND TYPES OF SOILS TO BE TESTED

(a) VOLUMETRIC CYLINDER



CUTTER ON SAMPLE JUST BEFORE CUTTING

CUTTER PARTIALLY FORCED DOWN INTO SAMPLE

(b) VOLUMETRIC CYLINDER OF SPLIT-RING TYPE, SHOWING METHOD OF USE

Figure 2. Examples of volumetric cylinders

made with an accuracy which will result in a volumetric error, dV/V, of less than 1 percent. The volumetric error is represented by the expression:

$$\frac{dV}{V}, \text{ percent} = 200 \frac{dD}{D} + 100 \frac{dH}{H}$$

where dH = accuracy of height measurement
dD = accuracy of diameter measurement

(3) Center the volumetric cylinder on top of the sample. The sample may be roughly trimmed to a size somewhat larger than the cylinder (see Fig. 2b) or the entire available sample may be used (see Fig. 3). Push the cylinder vertically into the sample not more than 1/4 in. and carefully trim the soil from the edge of the cylinder (see Fig. 3). Repeat the operation until the specimen protrudes above the top, of the calibrated cylinder. Care should be taken that no voids are formed between the cylinder and specimen. Using a wire saw for soft specimens and a knife, straightedge, or other convenient tool for harder specimens, trim the top of the specimen flush with the top of the cylinder. Invert the specimen, place it on a glass plate, and trim the bottom of the specimen.

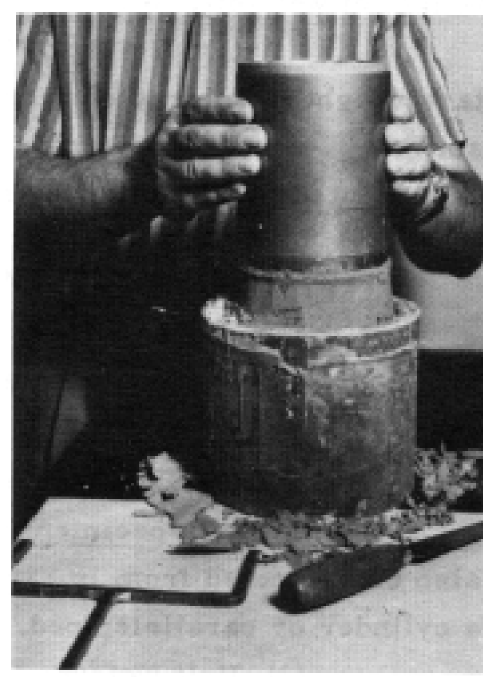


Figure 3. Determining the unit weight of a soil specimen with the volumetric cylinder (split-ring type)

(4) Remove the specimen from the volumetric cylinder using a guide cylinder, if available, and place it in a container. Weigh the specimen and container and record this weight

on the data sheet as the weight of tare plus wet soil. Alternatively, the wet weight of the specimen may be determined by weighing the volumetric cylinder with the specimen therein and then removing the material and placing it in a container for a water content deter.mination.

(5) Place the soil and container in an oven and oven-dry the specimen at 110 C ± 5, allow it to cool, and then weigh. Record this weight as weight of tare plus dry soil.

d. Computations. (1) Quantities obtained in test. The following quantities are obtained in the test.

(a) Weight of tare (specimen container or cylinder) plus wet soil The tare weight is subtracted from this value to obtain the weight of wet soil, W.

(b) Weight of tare (specimen container plus dry soil. The tare weight is subtracted from this value to obtain the weight of dry soil, W_s, or if the alternate procedure is used, dry weight of specimen is computed by the following formula:

$$\text{Dry weight of specimen} = \frac{\text{wet weight of specimen}}{1 + \left(\frac{\text{water content of specimen}}{100}\right)}$$

$$W_s = \frac{W}{1 + 0.01w}$$

(c) The inside volume of the volumetric cylinder. Volume, V, of the wet soil specimen is equal to this volume. The volume, V, may also be computed from linear measurements of a specimen in the form of a cylinder or parallelepiped.

(2) Unit weights. The wet unit weight, γ_m, and the dry unit weight, γ_d, expressed in terms of pounds per cubic foot, are computed by the following formulas:

$$\text{Wet unit weight} = \frac{\text{weight in g of wet specimen}}{\text{volume in cc of wet specimen}} \times 62.4$$

$$\gamma_m = \frac{W}{V} \times 62.4$$

$$\text{Dry unit weight} = \frac{\text{weight in g of dry specimen}}{\text{volume in cc of wet specimen}} \times 62.4$$

$$\gamma_d = \frac{W_s}{V} \times 62.4$$

(3) Void ratio. The void ratio, e , is computed by the following following formula:

$$\text{Void ratio} = \frac{\text{volume in cc of wet specimen} - \text{volume in cc of solids}}{\text{volume in cc of solids}}$$

$$e = \frac{V - V_s}{V_s}$$

where V_s = volume of solids = $\frac{W_s}{G_s}$

G_s = specific gravity of solids (see Appendix IV, SPECIFIC GRAVITY)

(4) Porosity. The porosity, n, is computed by the following formula:

$$\text{Porosity, percent} = \frac{\text{volume in cc of wet specimen} - \text{volume in cc of solids}}{\text{volume in cc of wet specimen}} \times 100$$

$$n\text{, percent} = \frac{V - V_s}{V} \times 100$$

(5) Degree of saturation. The degree of saturation, S, is computed by the following formula:

$$\text{Degree of saturation, percent} = \frac{\text{volume in cc of water}}{\text{volume in cc of wet specimen} - \text{volume in cc of solids}} \times 100$$

$$S\text{, percent} = \frac{V_w}{V - V_s} \times 100$$

where $V_w = W_w$ = difference between the wet weight of the soil specimen and the oven-dried weight

In the metric system, the volume of water, V_w, is approximately equal numerically to the weight of water, W_w.

4. DISPLACEMENT METHOD. a. Description. The displacement method consists of determining the total volume of a soil by measuring the volume or weight of water displaced by the soil mass. The method is particularly adaptable to irregularly shaped specimens and soils containing gravel, shells, etc.

b. Apparatus. The apparatus should consist of the following:

(1) Balance, sensitive to 0.1 g.

(2) Wire basket of sufficient size to contain the soil specimen.

(3) Can, or container, of sufficient size to submerge the wire basket and specimen.

(4) Oven (see Appendix I, WATER CONTENT - GENERAL).

(5) Specimen container. The container should be of metal that is resistant to corrosion, Seamless aluminum pans with lids are satisfactory.

(6) Paintbrush.

(7) Microcrystalline wax or paraffin.†

(8) Container for melting wax, preferably with a self-contained thermostat.

(9) Thermometer, range 0 to 50 C, graduated in 0.1 deg.

c. Procedure. The procedure shall consist of the following steps:

(1) Record all identifying information for the sample, such as

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† Among the many microcrystalline waxes found satisfactory are Product 2300 of the Mobil Oil Company, Microwax 75 of the Gulf Oil Corporation, and Wax 1290 of the Sun Oil Company. Paraffin alone is not as suitable for sealing soil specimens because its brittleness and shrinkage upon cooling will cause cracking, especially in thin sections and at corners; a mixture of 50 percent paraffin and 50 percent petrolatum has properties that approach those of a microcrystalline wax.

project, boring number, or other pertinent data, on the data sheet (Plate II-2).

(2) Determine, if not previously established, the specific gravity of the wax to be used. (About 0.9 g per cc, but should be determined for each batch of wax.)

(3) Cut a specimen from the sample to be tested. (The size of the specimen is not very important provided the capacity of the balance is not exceeded. In general, more accurate results will be obtained with larger specimens.) Trim the specimen to a fairly regular shape, Re-entrant angles should be avoided, and any cavities formed by large particles being pulled out should be patched carefully with material from the trimmings.

(4) Determine and record the wet weight of the soil specimen.

(5) Cover the specimen with a thin coat of melted wax, either with a paintbrush or by dipping the specimen in a container of melted wax. Apply a second coat of wax after the first coat has hardened. The wax should be sufficiently warm to flow when brushed on the soil specimen, yet it should not be so hot that it penetrates the pores of the soil. If hot wax comes in contact with the soil specimen it may cause the moisture to vaporize and form air bubbles under the wax.

(6) Determine and record the weight of the wax-coated specimen in air.

(7) Determine and record the submerged weight of the wax-coated specimen. This is done by placing the specimen in a wire basket hooked onto a balance and immersing the basket and specimen in a can of water as shown in Figure 4. In order to directly measure the submerged weight of the wet soil and wax, the balance must have been previously balanced with the wire basket completely submerged in the can of water. Ensure that the specimen is fully submerged, and that the basket is not touching the sides or bottom of the container. Measure the temperature of the water.

(8) Remove the wax from the specimen. It can be peeled off

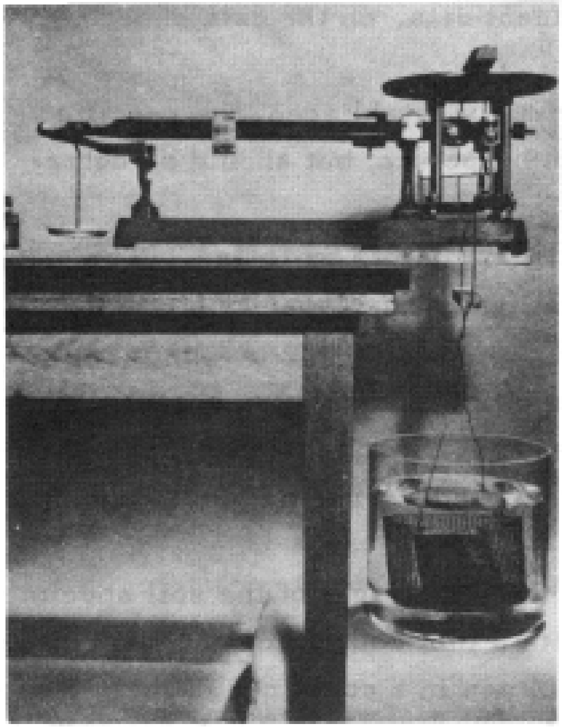

Figure 4. Determining the weight of a wax-coated specimen submerged in water

after a break is made in the wax surface. Use the entire sample, or as much as is free of wax inclusions, for a water content determination (see Appendix I, WATER CONTENT - GENERAL).

d. Computations. The following quantities are obtained directly in the test:

(1) Weight of uncoated specimen, W.

(2) Weight of soil plus wax. The weight of uncoated specimen, W, is subtracted from this value to obtain the weight of wax.

(3) Weight of soil plus wax in water.

The following computations shall be made:

(1) Divide the weight of the wax by its specific gravity. This gives the volume of the wax.

(2) Subtract the weight of the wax-coated specimen in water from its weight in air. The difference divided by the density of water at the test temperature (see Table IV-1, Appendix IV, SPECIFIC GRAVITY) is numerically equal to the volume of the coated specimen in cubic centimeters.

(3) Subtract the volume of wax from the volume of the coated specimen to obtain the total volume of the soil specimen, V.

(4) Compute the water content of the specimen (see Appendix I, WATER CONTENT - GENERA-L). If the entire specimen is used for the water content determination, obtain the dry weight of specimen, W_s, directly. If only a portion of the initial specimen is used for the water

content determination, compute the dry weight of specimen according to the following formula:

$$\text{Dry weight of specimen} = \frac{\text{wet weight of uncoated soil}}{1 + \left(\frac{\text{water content of wet soil}}{100}\right)}$$

$$ws = \frac{W}{1 + \frac{w}{100}}$$

Based on the above information, compute the unit weights, void ratio, porosity, and degree of saturation as specified hereinbefore.

5. POSSIBLE ERRORS. Following are possible errors that would cause inaccurate determinations of the total volume:

a. Volumetric Method.. (1) Imprecise measurement of volumetric cylinder (or of cylindrical specimen trimmed by other methods). Three height measurements and nine diameter measurements should be made to determine the average height and diameter of the cylinder. Precise calipers should be used for these measurements rather than flat scales.

(2) Voids formed on side of specimen by trimming beyond cutting edge.

(3) Material lost while removing specimen from cylinder.

b. Displacement Method. Voids on surface of specimen not filled by wax or air bubbles formed beneath wax.

UNIT WEIGHTS, VOID RATIO, POROSITY, AND DEGREE OF SATURATION
(VOLUMETRIC METHOD)

DATE ____________

PROJECT ____________

BORING NO. ____________

WATER CONTENT

SAMPLE OR SPECIMEN NO.						
TARE NO.						
WEIGHT IN GRAMS	TARE PLUS WET SOIL					
	TARE PLUS DRY SOIL					
	WATER	W_w				
	TARE					
	DRY SOIL	W_s				
WATER CONTENT		w	%	%	%	%

WEIGHT-VOLUME RELATIONS

SAMPLE OR SPECIMEN NO.						
CYLINDER NO.						
CENTI-METERS	HEIGHT OF CYLINDER	H				
	INSIDE DIAMETER OF CYLINDER	D				
WEIGHT IN GRAMS	WET SOIL AND TARE					
	TARE					
	WET SOIL	W				
	DRY SOIL†	W_s				
SPECIFITY GRAVITY OF SOIL		G_s				
VOLUME IN CC	WET SOIL (VOLUME OF CYLINDER)	V				
	DRY SOIL = W_s/G_s	V_s				
LB PER CU FT	WET UNIT WT = (W/V) 62.4	γ_m				
	DRY UNIT WT = (W_s/V) 62.4	γ_d				
VOID RATIO = $(V - V_s)/V_s$		e				
POROSITY, % = $\left[(V - V_s)/V\right] \times 100$		n	%	%	%	%
DEGREE OF SATURATION, % = $\left[V_w/(V - V_s)\right] \times 100$		S	%	%	%	%

VOLUME OF CYLINDER, $V = \frac{\pi D^2 H}{4}$

VOLUME OF WATER = $V_w = \frac{W_w}{\text{SPECIFIC GRAVITY OF WATER‡}}$

† IF NOT MEASURED ON ENTIRE SPECIMEN, DRY WEIGHT MAY BE COMPUTED AS FOLLOWS: $W_s = \frac{W}{1 + 0.01\ w}$

‡ SPECIFIC GRAVITY OF WATER IN METRIC SYSTEM = 1 (APPROX)

REMARKS ____________

TECHNICIAN ____________ COMPUTED BY ____________ CHECKED BY ____________

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PLATE II-1

UNIT WEIGHTS, VOID RATIO, POROSITY, AND DEGREE OF SATURATION
(DISPLACEMENT METHOD)

DATE ____

PROJECT ____

BORING NO. ____

WATER CONTENT

SAMPLE OR SPECIMEN NO						
TARE NO						
WEIGHT IN GRAMS	TARE PLUS WET SOIL					
	TARE PLUS DRY SOIL					
	WATER	W_w				
	TARE					
	DRY SOIL	W_s				
WATER CONTENT		w	%	%	%	%

WEIGHT-VOLUME RELATIONS

SAMPLE OR SPECIMEN NO.						
TEST TEMPERATURE OF WATER, T, C						
WEIGHT IN GRAMS	SOIL AND WAX IN AIR					
	WET SOIL	W				
	WAX					
	WET SOIL AND WAX IN WATER					
	DRY SOIL†	W_s				
SPECIFIC GRAVITY OF SOIL		G_s				
VOLUME IN CC	WET SOIL AND WAX‡					
	WAX					
	WET SOIL	V				
	DRY SOIL = W_s/G_s	V_s				
LB PER CU FT	WET UNIT WT = (W/V) 62.4	γ_m				
	DRY UNIT WT = (W_s/V) 62.4	γ_d				
VOID RATIO = $(V - V_s)/V_s$		e				
POROSITY, % = $[(V - V_s)/V] \times 100$		n	%	%	%	%
DEGREE OF SATURATION, % = $[V_w/(V - V_s)] \times 100$		S	%	%	%	%

VOLUME OF WAX = $\frac{\text{WEIGHT OF WAX}}{\text{SPECIFIC GRAVITY OF WAX}}$ = ____

† IF NOT MEASURED DIRECTLY, MAY BE COMPUTED AS FOLLOWS: $W_s = \frac{W}{1 + 0.01\ w}$

‡ VOLUME OF WET SOIL AND WAX = $\frac{\left(\text{WEIGHT OF WET SOIL AND WAX IN AIR}\right) - \left(\text{WEIGHT OF WET SOIL AND WAX IN WATER}\right)}{\text{DENSITY OF WATER AT TEST TEMPERATURE}}$

REMARKS ____

TECHNICIAN ____ COMPUTED BY ____ CHECKED BY ____

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PLATE II-2